3 Conservation Practices: Relation to the Management of Plant Nutrients for Crop Production[1]

R. F. Follett, S. C. Gupta, and P. G. Hunt[2]

Increased use of conservation practices, especially conservation tillage, helps sustain or enhance the productivity of soil resources by reducing soil erosion losses of plant nutrients and soil organic matter. This change in cropland management, from almost complete turning of the surface soil, has occurred primarily since 1970 in the USA. The change has been encouraged by a national concern for erosion control and maintenance of soil productivity, but offers opportunities for improved farm profitability through reduced resource input. This chapter focuses on the USA because of the accessibility of information. The topics discussed, however, are also pertinent to other countries.

The type of crop production system selected can especially influence soil fertility and organic matter because of effects on the soil's biological, chemical, and physical components. *Soil fertility* refers to the capability of the soil to supply nutrients that enhance plant growth. *Soil productivity* is the soil's ability to produce a crop. Productivity is a function of a soil's natural fertility plus nutrients added as fertilizer, organic residues, and other sources; soil physical and biological properties; climate; management; and other non-inherent factors used to produce crops (Follett and Wilkinson, 1985). Soil organic matter concentration is a critical component of soil productivity that can be changed by altering cropland management practices. This is important because organic matter improves soil-fertility, -tilth, and -erosion control; water-infiltration and storage; and the soil's ability to bind and promote microbial breakdown of toxic substances. The dynamic effect of soil organic matter suggests that perhaps the best opportunity for sustaining or enhancing the long-term fertility and productivity of our cropland soils can be achieved by

[1] Contribution from the Soil-Plant-Nutrient Research Unit, USDA-ARS, Fort Collins, CO and Coastal Plains Soil and Water Conservation Research Center, Florence, SC 29501, in cooperation with the Dep. of Soil Science, Univ. of Minnesota, St. Paul, MN.

[2] Soil scientist, USDA-ARS, P.O. Box E, Fort Collins, CO 80522; Associate professor of soil science, Univ. of Minnesota, St. Paul, MN 55108; and soil scientist, USDA-ARS, P.O. Box 3039, Florence, SC 29501, respectively.

improving management of this soil component. This can be accomplished by developing improved conservation tillage practices that effectively utilize crop residues, as well as other added organic and/or inorganic crop production components.

The objectives of this chapter are to: (i) provide an overview of the use of conservation tillage in the USA; (ii) review plant nutrient sources (i.e., fertilizer, organic residues, and symbiotic N_2 fixation); (iii) discuss the ways in which conservation tillage and emerging cropping systems need to influence plant nutrient management; and (iv) discuss current and future issues relative to assessing the effectiveness of soil conservation practices for their effects on soil fertility.

CONSERVATION TILLAGE IN THE USA

Conservation tillage is generally an umbrella term to describe tillage practices that conserve soil and water (Mannering and Fenster, 1983). The Soil Conservation Society of America's (1982) *Resource Conservation Glossary* defines conservation tillage as "any tillage system that reduces loss of soil or water relative to conventional tillage; often a form of non-inversion tillage that returns protective amounts of residue mulch on the surface." *No-Till Farmer* magazine (Christensen and Magleby, 1983) uses the following definitions.

1. *Conventional tillage*—Where 100% of the topsoil is mixed or inverted by plowing, power tillering, or multiple disking.
2. *Minimum tillage*—Limited tillage, but where the total field surface is worked by tillage equipment.
3. *No-till*—Only the intermediate seed zone is prepared. Approximately 25% of the surface area could be worked. It could be no-till, till plant, chisel plant, or rotary-strip plant. It includes forms of conservation and mulch tillage.

Recently, Magleby et al. (1985) reported that The Conservation Tillage Information Center (CTIC), *No-Till Farmer* magazine, The National Resources Inventory (NRI), and Farm Production Expenditure Survey (FPES) estimated the amount of land under conservation tillage was 35.1, 36.9, 34.3, and 24.5 million ha; respectively. Conservation tillage includes the minimum and no-till categories as defined by *No-Till Farmer*. By contrast, CTIC uses a definition of conservation tillage to include tillage planting systems in which 30% or more of the surface is covered with residue just after planting (Conservation Tillage Information Center, 1985). Since each of the above sources uses a different information base for arriving at its estimate and the NRI estimate is for 1982, it is not surprising that their estimates differ. Yet, three of the sources were generally similar. Estimates by FPES may have been low because of the procedures used or as a result of not accounting for conservation tillage applied to planted acreage diverted to U.S. government programs. Since the *No-Till Farmer* magazine (Lessiter, 1974, 1975, 1977, 1979, 1981, 1983, 1985) provides annual data on changes in tillage practices nationally for the last several years, their data and definitions are most useful for the purposes of this chapter.

Table 3–1 shows the changes in the use of various tillage systems nationally from 1973 through 1985 (estimated). During this 13-yr period, the percentage of the total tilled area devoted to conservation tillage (minimum plus no-till) has nearly doubled (from 18 to 35%) while the percentage in conventional tillage has decreased from 82 to 65%.

Figure 3–1 shows that the use of conservation tillage varies widely among the 10 farm production regions of the USA as adapted from Christensen and Magleby (1983) for 1981. We chose 1981 for our illustration because it was a stable crop production year and the data avoids the impacts on land use patterns due to recent U.S. government programs such as Payment in Kind (PIK), (USDA, 1984) and recent severe financial distress of U.S. farmers (USDA, 1985a). Percentage of cropland area in conservation tillage (minimum plus no-till) is highest in the Southeast, Northeast, and Appalachian regions. The Corn Belt, Northern Plains, and Mountain regions all have about one third of their cropland area under conservation tillage. The largest areas in conservation tillage are in the Corn Belt (11.6 million ha) and Northern Plains (10.7 million ha) (Fig. 3–1).

TILLAGE MANAGEMENT REGIONS

The amount of conservation among the various crop production regions depends on a number of factors including soil types, climate, crops, and general cropping practices. Because of the importance of these factors to the adoption of conservation tillage, Allmaras et al. (1985)

Table 3–1. Various tillage systems used in the continental USA from 1973 to 1985.

Year	Total hectares tilled†		
	Minimum	No-till	Conventional
	%		
1973	15.8	2.0	82.2
1974	17.0	2.1	80.9
1975	17.6	2.4	80.0
1976	18.4	2.7	78.9
1977	21.0	2.5	76.5
1978	22.7	2.4	74.9
1979	23.9	2.5	73.6
1980	27.5	2.4	70.1
1981	29.1	2.9	68.0
1982	31.7	3.7	64.6
1983	35.0	4.0	61.0
1984	25.8	4.5	69.7
1985 (estimate)	29.9	5.0	65.1

†Based upon summation of acres in minimum, no-till, and conventional practices as reported in *No-Till Farmer* (Lessiter, 1974, 1975, 1977, 1979, 1981, 1983, 1985).

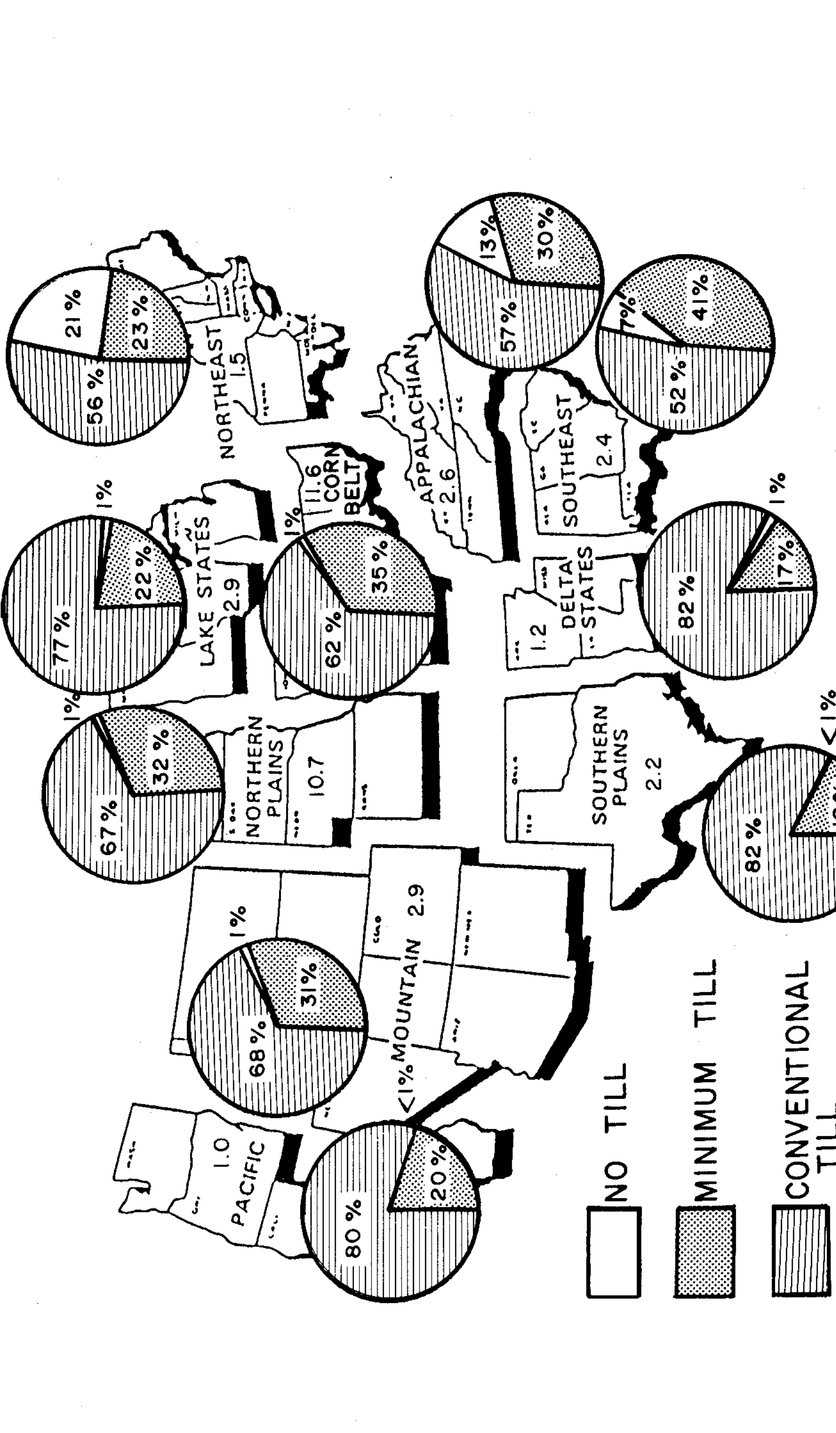

Fig. 3–1. Percentages of land in various tillage and millions of hectares of conservation tillage (minimum tillage plus no-till) by farm production region in 1981. Adapted from Christensen and Magleby (1983).

recently identified seven Tillage Management Regions (TMRs) across the USA (Fig. 3–2).

Their identification of land areas into TMRs corresponded to land resource regions (LRRs) or in some instances into major land resource areas (MLRAs) (USDA, 1981b). Within a TMR, soil type, local weather conditions, and crop rotations will vary. In addition, primarily rainfed agriculture is considered since irrigated agriculture may have a different sensitivity to the environment in the TMR. The bases on which the TMRs were developed include conservation and tillage needs and functions of conservation tillage. For example, depending upon soil types, topographic characteristics, and other factors, improved water conservation and use and water erosion control are major conservation needs in all of the TMRs. Wind erosion control is a major conservation need in the Northern and Southern Plains, Pacific Northwest, and Corn Belt. Soil temperature management is important in the Corn Belt and the Northern Great Plains to overcome cold soil conditions. In addition, soil drainage is a major need in the Corn Belt and management of restrictive soil layers is important in the Coastal Plains and Corn Belt TMRs (Allmaras et al., 1985). All of these needs can be influenced by the type of tillage management being used. Expected conservation and tillage needs are related to the climate and principal crops shown in Table 3–2.

Production agronomists have several management options for developing successful soil-crop managment systems. These options include tillage, residue placement, fertilization, crop rotation, and pest control practices. One change in a component of the integrated system may sig-

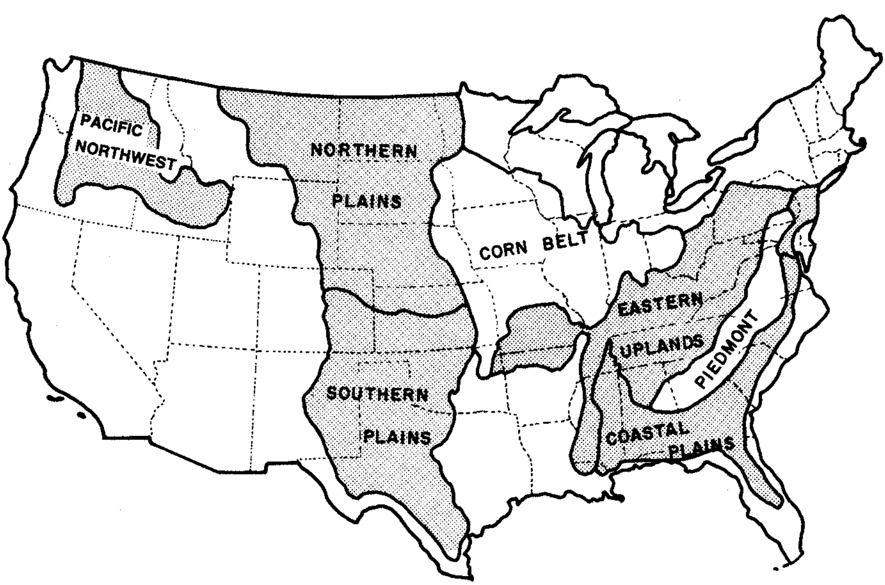

Fig. 3–2. Tillage management regions (TMRs) in the conterminious USA (Allmaras et al., 1985).

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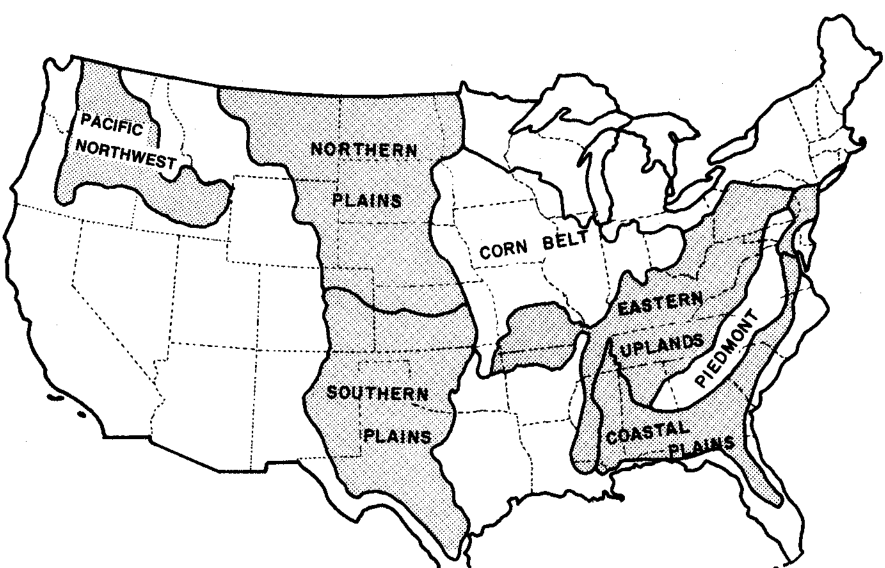

Fig. 3–2. Tillage management regions (TMRs) in the conterminious USA (Allmaras et al., 1985).

Table 3–2. Climatic characteristics, major crops, and typical major land resource areas (MLRAs) (USDA, 1981b) in seven tillage management regions (TMRs) of the USA (Allmaras et al., 1985).

Tillage management region	Typical MLRAs†	Mean monthly temperature‡ January	Mean monthly temperature‡ July	Mean annual pan evaporation‡	Mean annual precipitation‡	Frost-free season‡	Growing season annual precipitation	Major crops
		———— ° C	————	——— cm	———	days	%	
Corn Belt	103,104,106,107 108,110,111,114	−5 −10 to 0	22 20 to 25	80 70 to 100	80 50 to 100	180 130 to 230	50	Maize, soybean, wheat, hay, feed grains
Eastern Uplands	121,134,147	3 0 to 10	22 20 to 27	100 70 to 100	120 90 to 150	190 120 to 280	<50 in south >50 in north	Cotton, maize, soybean, small grain
Piedmont	136,148	5 0 to 10	24 20 to 25	90 80 to 100	120 90 to 150	200 160 to 240	<60	Maize, wheat, grain, sorghum, soybean, forages, cotton
Coastal Plains	133A	8 5 to 10	25 25 to 27	105 100 to 120	130 100 to 155	240 200 to 280	>60 in east <60 in west	Maize, soybean, grain, sorghum, small grains, cotton

(continued on next page)

Table 3–2. Continued.

Tillage management region	Typical MLRAs†	Mean monthly temperature‡ January	Mean monthly temperature‡ July	Mean annual pan evaporation‡	Mean annual precipitation‡	Frost-free season‡	Growing season annual precipitation	Major crops
		° C	° C	cm		days	%	
Southern Great Plains	73,77,78	5 −3 to 10	27 26 to 28	150 120 to 190	60 40 to 100	170 130 to 250	>70	Wheat, maize, soybean, grain, sorghum, cotton, forages.
Northern Great Plains	55B,56,72,75	−10 −15 to 3	22 20 to 25	90 70 to 130	40 25 to 60	130 100 to 160	>70	Wheat, maize, soybean, grain, sorghum, sunflower, feed grains, forages
Pacific Northwest	7,8,9	0 −5 to 0	18 15 to 20	90 80 to 100	35 15 to 60	160 100 to 200	>45	Wheat, peas, barley, lentils

†Major land resources areas are (7) Columbia Basin, (8) Columbia Plateau, (9) Palouse Nez-Perce Prairie, (55B) Central Black Glaciated Plains, (56) Red River Valley, (72) Central High Tableland, (73) Rolling Plains and Breaks, (75) Central Loess Plains, (77) Southern High Plains, (78) Central Rolling Plains, (103) Central Iowa and Minnesota Till Prairies, (104) Eastern Iowa and Minnesota Till Prairies, (106) Nebraska and Kansas Loess-Drift Hills, (107) Iowa and Missouri Deep Loess Hills, (108) Illinois and Iowa Deep Loess Drift, (110) Northern Illinois and Indiana Heavy Till Plain, (111) Indiana and Ohio Till Plain, (114) Southern Illinois and Indiana Thin Loess and Till Plain, (121) Kentucky Bluegrass, (133A) Southern Coastal Plains, (134) Southern Mississippi Valley Silty Uplands, (136) Southern Piedmont, (147) Northern Appalachian Ridges and Valleys, and (148) Northern Piedmont.

‡These observations are arranged to show characteristic value on first line and range on second line.

nificantly impact the performance of the entire system to accomplish certain functions for which it is intended.

For example, conservation tillage systems can perform certain functions as Follett and Bauer (1986) describe including: (i) controlling rill and inter-rill erosion, (ii) conveying runoff water non-erosively, (iii) preventing wind erosion, (iv) protecting soil fertility, (v) maintaining soil organic matter, (vi) enhancing root-zone characteristics for plant growth, (vii) improving water infiltration, (viii) soil temperature management, and (ix) possibly others such as pest control. Addressing the major conservation needs of the various TMRs requires that many of the above functions be accomplished simultaneously.

Considerable progress has been made concerning the development of conservation and tillage systems to accomplish functions associated with soil physical components. In the future, increased emphasis is needed to identify and accomplish functions associated with the protection and improvement of the soil fertility component of soil productivity.

NUTRIENT RESOURCES

Figure 3–3 schematically presents nutrient sources in crop production systems and the components of plant nutrient cycling that conservation practices influence. In Figure 3–3, the plant nutrients that are influenced by conservation practices are those already present in the soil and those added or returned to the soil at a time when the conservation

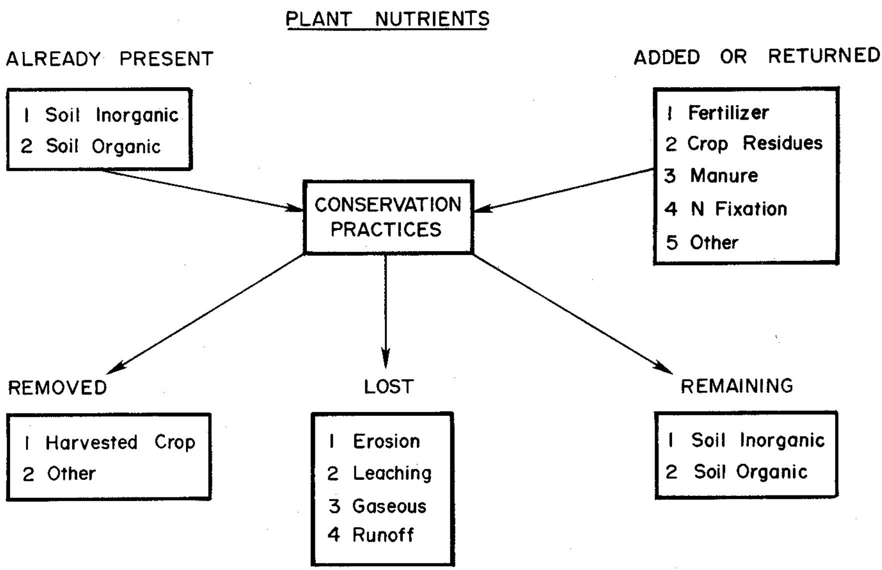

Fig. 3–3. Conceptual role of conservation practices in the management of plant nutrients and their eventual redistribution and fate.

practice(s) can influence what happens to them. To the degree that there is an effect by conservation practice, it is on those plant nutrients removed in harvested crops, lost to the environment, and/or remaining in the soil at the end of a given time period.

The relationship in Fig. 3–3 that shows the effect of conservation practices on soil fertility can be described as a nutrient budget in Eq. [1], as follows:

$$RN_{tn} = \sum_{t}^{tn}(AP_t + AR_{\Delta t} - RM_{\Delta t} L_{\Delta t} \qquad [1]$$

where

RN = soil inorganic and organic nutrients remaining at time (tn),
AP = soil inorganic and organic nutrients present at time t,
AR = inorganic and organic nutrients added or returned to the soil during the time interval Δt,
RM = plant nutrients removed with the harvested product during the time interval Δt,
L = inorganic and organic nutrients lost during the time interval Δt,
t = the beginning time for imposing and determining the effectiveness of the conservation practice(s) used for conserving plant nutrients,
tn = the ending time for determining the effectiveness of the conservation practices used for conserving plant nutrients, and
Δt = The time interval between t and tn.

If $RN_{tn} \geqq AP_t$, then the reservoir of plant nutrients in the soil should be maintained or increased by the conservation practices being used. Useful indices such as increased organic carbon or organic nutrient (nutrients in soil organic matter) content may reflect this relationship. In addition, some interpretation might be made of the degree to which soil productivity is being maintained or even enhanced. Even if $RN_{tn} < AP_t$, it may not be of major concern depending upon their rates of change. Also, if $RM_{\Delta t}$ is larger and $L_{\Delta t}$ is smaller than they were before the use of conservation practices was begun, then removal of harvested crop yields would be larger while losses from the soil-plant system would be smaller because of the conservation practices. The most desirable combination of relationships is for $RN_{tn} \geqq AP_t$, while $RM_{\Delta t}$ increases and $L_{\Delta t}$ decreases.

Other relationships can be developed from Eq. [1] and the concepts shown in Fig.3–3. Irrespective, it is increasingly important to begin establishing the functions desired of conservation practices for cropland and the criteria whereby the effectiveness of the conservation practices can be measured, evaluated, and hopefully improved.

The discussion that follows will present quantitative information from the USA for some parts of Fig. 3–3. In general, quantitative information is given where we are reasonably confident that: (i) the methods used to arrive at those data can be substantiated (i.e., nutrients added or returned in fertilizer and crop residues), (ii) the relative values provide a perspective on how conservation practices influence the management of nutrient resources (e.g., controlling soil erosion), and (iii) the values given will not be misleading.

Nutrients Already Present in Cropland

Generally, there is a lack of any coherent soil test data base that can be used to assess inherent soil fertility and soil nutrient status on a nationwide basis. Existing data bases are often presented as a percent of samples in high, medium, and low fertility status. Thus, we did not try to estimate total quantities of inorganic- and organic-soil nutrients found on cropland on either a national or regional basis. Irrespective, the nutrient quantities that exist are enormous, but not inexhaustible. They are, perhaps, among any nation's most valuable resources and serve as a vast reservoir through which both inorganic and organic nutrients are added and/or returned to cropland soils.

Soil supplies 13 of the 16 elements that are known to be essential for crop growth of which N, P, and K are most commonly deficient in agricultural soils. Secondary- and micro-nutrient deficiencies have been widely documented in some soils, with S, Zn, and B being the most common. In order to maintain high crop yields, the addition and release of nutrients, particularly N, P, and K must be in balance so that the nutrients are always at a level of availability to attain economic (preferably maximum) yields.

With plowing and secondary tillage operations, the rate of decay of soil organic matter and release of its associated nutrients is related to the proportion of old and new humus, aeration, moisture, and temperature (Lucas et al., 1977). Reduced tillage and especially no till, when used continuously for several years, can result in soils that have higher organic matter than those that are plowed (Blevins et al., 1977; Lamb et al., 1985; Stanford et al., 1973). Additions of organic residues are a major factor in maintaining or increasing soil organic matter (Power and Legg, 1978). Larson et al. (1972, 1978) demonstrated that, after 11 yr, soil organic carbon content was a linear function of the amount of crop residue added (Fig. 3–4) in Iowa. It was estimated that about 5 Mg ha^{-1} of crop residues were needed to maintain the original C content in the soil under conventional (plowed) tillage conditions. Rasmussen (1980) reported the same observation and estimate in Oregon, based upon a 45-yr experiment sampled at 11-yr intervals. It is likely that under conservation tillage conditions, lower amounts of crop residues would be required to maintain the original C content in the soil. Addition of N fertilizer and consequent higher dry matter production also help increase and maintain higher levels of soil organic matter (Blevins et al., 1983; Meisinger et al., 1985).

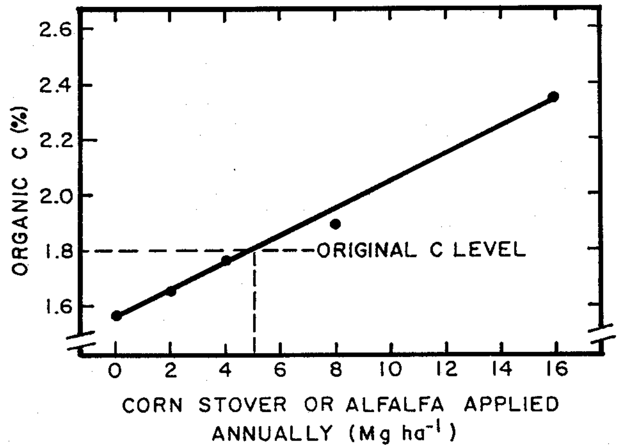

Fig. 3–4. Carbon content of a Typic Hapludoll as influenced by amounts of corn stover or alfalfa hay added to the soil for each of 11 consecutive yr. Soil was cropped to maize with conventional tillage (Larson et al., 1978).

Nutrients Added or Returned to Cropland

Fertilizer

Fertilizer is defined as *"any organic or inorganic material of natural or synthetic origin which is added to a soil to supply certain elements essential to the growth of plants"* (Soil Conservation Society of America, 1982). For purposes of this discussion, inorganic materials or commercial fertilizers are referred to in this chapter. The use of such fertilizers is now an economic necessity on most cropland soils. For example, yield increases of maize (*Zea mays* L.) attributed to increases in fertilizer use range from 20 to 50% (Walsh, 1985). Fertilizers represent the major input of added nutrients to croplands. Addition of fertilizers to the soil result in increased soil solution nutrient concentrations at the point of application; therefore those nutrients are highly available for plant uptake. In addition, commercial fertilizers are the most controllable source of nutrients for crop production. Through the use of appropriate rates, placement, sources, and application times of fertilizer, it is possible to supply nutrients reasonably close to economically optimum levels. In contrast, it is difficult to fine-tune the amount or timing of soil organic or inorganic nutrient release to optimize availability for crop uptake.

When the cost of applied fertilizer is low relative to the value of the crops, there is strong incentive to avoid any deficiencies and the use of larger fertilizer amounts per unit of yield response are made than for crops of lower relative value. Thus, certain crops, such as vegetables, may often be over-fertilized and inefficient use of fertilizers may result. Furthermore, differences exist in the ability of different crops to absorb nutrients from the soil. Plants vary greatly in their ability to take up applied fertilizers (especially N). For example, N fertilizer uptake efficiency for lettuce (*Lactuca sativa* L.) may only be 12 to 25% while for maize it may be close to 50% (Broadbent, 1985). Among the plant characteristics influencing nutrient uptake are nature and extent of root system, rate of crop growth, nutrient requirements during the growing season, and duration of crop growth.

A good soil-testing program is essential to sound fertilizer use. The soil test value is the starting point. Soil test is a means to evaluate the ability of the soil to supply these nutrients. Soil tests also evaluate carryover levels of past fertilizer programs. More carryover can be expected with high application rates and following droughty years. Nutrient carryover from manured soils and from the return of crop residues may also occur since not all of the nutrients are released during the 1st yr after application.

Figure 3–5 shows the increase in the use of commercial fertilizers for supplying N, P, and K to crops in the USA since 1955 (Hargett and Berry, 1985; USDA, 1981a, 1985b). Commercial fertilizer use on cropland began to increase most rapidly in the period following the end of World War II. In 1954, about 30% of all harvested crops and cropland pasture in the USA received fertilizer (Adams et al., 1958). In 1947 and 1954, estimates were that 44 and 60% of the harvested cropland planted to maize and 18 and 28% of the harvested cropland planted to wheat (*Triticum aestivum* L.) were fertilized, respectively. Average N, P, and K rates of fertilization for maize in 1954 were 30, 14, and 23 kg ha^{-1} and for wheat were 30, 13, and 18 kg ha^{-1} (Adams et al., 1958) In 1984, 97 and 76% of the harvested cropland planted to maize or wheat received

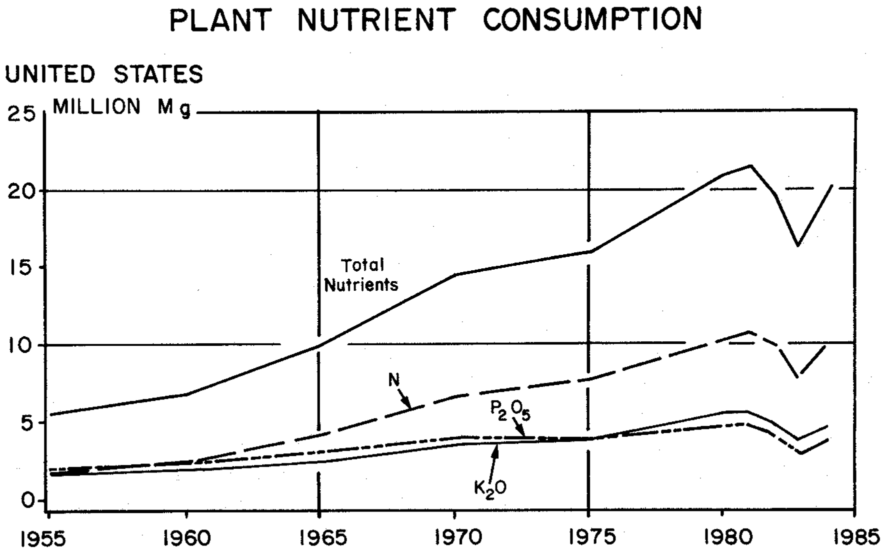

Fig. 3–5. Plant nutrient consumption in the USA between 1955 and 1984 (Hargett and Berry, 1985; USDA, 1981a, 1985a).

fertilizer, respectively. Average N, P, and K rates of fertilization for maize in 1984 are estimated to be 155, 32, and 81 kg ha^{-1} and for wheat 70, 18, and 43 ka ha^{-1}, (USDA, 1985b). Table 3–3 shows the 1977 use of fertilizer N, P, and K by crop production region (USDA, 1981a). The year 1977 was chosen to more nearly correspond with the data for manure and crop residues shown in Tables 3–4 and 5, as well as to avoid the period of economic distress for U.S. farmers that has occurred since 1982 (USDA, 1985a, 1985b).

Organic Residues

Organic residues are a tremendous natural resource for providing plant nutrients and C to help maintain soil fertility, organic matter, and tilth of soils. Organic residue, as well as fertilizers, are important nutrient sources. This discussion will address primarily N, P, and K. The organic residues available in the USA for use on soils include livestock wastes, crop residues, sewage sludge and septage, food processing wastes, industrial organic wastes, logging and wood manufacturing wastes, and municipal refuse. Estimates are that, of total annual production of organic wastes, animal manure and crop residues account for about 22 and 54%, respectively (USDA, 1978). All other organic waste sources, in terms of current land use and probability of increased use, account for < 1% of the total organic waste production in the USA or else they have a low to very low probability for increased use on agricultural lands (USDA, 1978). Therefore, this part of the discussion will deal only with animal manure and crop residues.

Animal Manure—Manure from animals represents about 22% of all organic wastes produced in the USA and refers to feces and urine excreted by dairy or beef cattle (*Bos taurus*), horses (*Equus caballus*), sheep (*Ovis aries*), goats (*Capra hircus*), swine (*Sus scrofa domesticus*), chickens (*Gallus gallus domesticus*), turkeys (*Meleagris gallopavo*), and ducks (*Anas*

Table 3–3. Use of fertilizer N, P, and K by farm production region in 1977 (USDA, 1981a).

Region	Fertilizer N	Fertilizer P	Fertilizer K
	Gg		
Northeast	312.1	122.9	248.8
Lake	854.9	247.0	701.9
Corn Belt	2808.2	730.8	1795.6
Northern Plains	1551.9	230.4	119.1
Appalachian	635.6	208.5	481.6
Southeast	818.9	192.4	594.1
Delta	442.5	94.0	201.4
Southern Plains	911.9	154.9	100.1
Mountain	467.1	107.7	28.5
Pacific	815.0	130.3	94.1
Total	9618.1	2218.9	4365.2

platyrhynchos domesticus). About 90% of the approximately 158 000 Gg of manure generated annually, under both confined and unconfined conditions, is reportedly used as a production resource on land (USDA, 1978). About 96 000 Gg is excreted on pasture, rangeland, and cropland and thus is automatically returned to the land. About 73% of the 62 000 Gg produced under confined conditions is applied to the land. Although animal manure has long been used to improve soil tilth and fertility, it is important to recognize that there may be a number of constraints on the use of manure on land (Gilbertson et al., 1979). These can include the costs of collection, processing, transportation, and application; environmental considerations; and site characteristics. The site constraints, especially in terms of manure disposal, are thoroughly reviewed by Norstadt et al. (1977) and Witty and Flach (1977).

Data presented in Table 3–4 show the total annual production of manure by livestock by crop production region. The amounts of N, P, K, and C returned to the soil are shown from manure that is produced under confined conditions and which can be returned to cropland as a resource that can be managed. Manure was assumed to be 32% C on a dry weight basis (McCalla et al., 1977). In addition, an unquantified amount of the manure produced under unconfined conditions is also excreted on cropland and thus returned automatically. Therefore, our assumption that all of the manure produced under confinement was returned to cropland is an appropriate, but likely conservative estimate of nutrients and C that are returned to cropland from both confined and unconfined manure (Table 3–4). The author's estimates do not differ greatly from Power and Papendick's (1985) estimates made previously.

Crop Residues—Crop residues include stems, leaves, roots, chaff, and other plant parts that remain after agricultural crops are harvested or grazed. According to a recent USDA survey (USDA, 1978), about 390 000 Gg of crop residues are produced in the continental USA annually by 15

Table 3–4. Total annual production of animal manure and estimated return of N, P, K, and C to the soil from manure produced under confined conditions by farm production region (USDA, 1978).

Region	Total annual production	Returned to the soil			
		N	P	K	C
	Gg	Gg			
Northeast	9 644	137.4	83.2	141.4	1 986.5
Lake	14 334	145.0	101.5	238.7	3 285.4
Corn Belt	28 253	127.8	94.6	183.8	2 197.5
Northern Plains	20 488	49.0	50.8	118.5	1 438.0
Appalachian	13 808	58.8	46.5	73.2	955.0
Southeast	11 188	49.8	47.5	51.1	671.7
Delta	8 196	32.9	33.9	34.6	440.4
Southern Plains	24 061	61.0	45.7	99.8	1 241.6
Mountain	16 127	67.4	33.1	82.2	1 066.6
Pacific	12 034	79.8	52.0	104.3	1 462.0
Total	158 133	808.9	588.8	1 127.6	14 744.6

major cultivated crops; this residue accounts for about 80% of the total crop residues produced. Larson et al. (1978) estimated that about 280 000 Gg of crop residues were produced by 10 major crops. Three major crops—field corn, soybean, and wheat—produce about 70% of all crop residues (USDA, 1978). The quantities of residues and amounts of N, P, K, and C produced and returned to the soil are estimated by multiplying the total grain (or crop) production by a grain (or crop) to residue weight ratio (Table 3–5) (USDA, 1978). Crop residues were assumed to be 40% C on a dry weight basis (Parr and Papendick, 1978).

Disposition of crop residues can include feeding to animals, use as fuel, return to the soil, collection and selling, and wasted (e.g., burned in place) (Stanford Research Institute, 1976). On a national basis, about 70% of the residues and nutrients in them are returned to the soil, mostly at the production site. If livestock bedding wastes were included in Table 3–5, about 5% more crop residue nutrients would be accounted for on a national basis as being returned to the soil. The greatest quantities of bedding wastes result from dairy operations. Crop roots are also an important crop residue, but again are not included in Table 3–5.

Symbiotic Nitrogen Fixation—For this discussion, symbiotically fixed N returned to cropland includes that returned by the major seed legumes and by one forage legume (alfalfa, *Medicago sativa* L.). Table 3–5 shows that about 3 000 Gg of N are returned to the soil with crop residues each year. Of that amount, seed legumes (soybean, *Glycine max* L. Merr.; dry bean, *Phaseolus* spp., and peanut, *Arachis hypogaea* L.) provide about 24% nationally or 720 Gg; of that amount, soybean account for 96% of the legume-N (USDA, 1978).

A number of questions exist concerning the significance of N_2 fixation by soybean. In Illinois, Johnson et al. (1974) showed that the percent of total N in soybean plants derived from symbiotic fixation decreased from about 48% when no fertilizer-N was added down to about 10% with the

Table 3–5. Production of crop residues and return of N, P, K, and C to the soil by farm production region in 1977 (USDA, 1978).

Region	Total annual production	Returned to the soil N	P	K	C
	Gg	Gg			
Northeast	10 145	76.7	10.6	85.4	2 694.6
Lake	40 365	294.0	42.4	332.8	10 462.6
Corn Belt	156 956	1 342.4	174.9	1 178.8	38 548.3
Northern Plains	73 960	484.9	63.2	640.8	22 395.2
Appalachian	15 676	161.2	19.3	132.4	4 376.6
Southeast	12 274	136.3	17.0	94.6	2 901.7
Delta	13 718	84.4	17.9	101.9	3 451.2
Southern Plains	29 691	181.5	22.4	219.5	7 589.0
Mountain	18 146	115.9	15.4	181.4	6 474.4
Pacific	18 337	109.2	13.3	163.6	5 977.9
Total	389 268	2 986.5	396.4	3 131.3	104 871.5

addition of 224 to 448 kg ha^{-1} of fertilizer N. Weber (1966) reported that with good growth conditions about 40% (72 kg ha^{-1}) of the N for soybean was symbiotically fixed on Midwestern soils. Ham et al. (1975) determined for Minnesota soils that soybean N_2 fixation provided only 34% and later Ham and Caldwell (1978) determined that symbiotic fixation by soybean provided only 25 to 27% of their N. More recently, Thurlow and Hiltbold (1985) indicate that estimates for Midwestern soils are too low for conditions in Alabama where 70% or more of the N for soybean is derived from the atmosphere. Hunt et al. (1985) for a 2-yr period in South Carolina estimated that the percentage of N supplied by N_2 fixation under either conventional or conservation tillage ranged between 49 and 67% for non-irrigated soybean. Under irrigation, Matheny and Hunt (1983) in South Carolina and Bezdicek et al. (1978) in Washington have reported that N_2 fixation by soybean accounted for up to 91 and 83% of total plant N, respectively.

In addition to questions concerning the percentage of the N that soybean symbiotically fixes from the atmosphere, there is also a question of estimation of amounts of soybean residues using straw to grain ratio. A straw to grain ratio of about 1.5:1.0 for soybean at harvest has been generally accepted in the literature (Larson et al., 1978). However, where ground litter is collected as it drops and is added back to the amount of standing plant material as part of the straw component, this ratio can change considerably. Hunt et al. (unpublished data) recently measured the straw to grain ratios, with ground litter included, to equal 2.7, 4.3, and 2.5 for three cultivars, respectively. Corresponding values for straw to grain ratio without the ground litter component were 1.2, 2.3, and 1.4 for the same three cultivars, respectively.

Based upon the above discussion, estimates can be made of the amounts of N reported in Table 3–3 that are derived from N_2-fixation. Generally accepted values for symbiotically fixed N would appear to be about 40 and 70% of the total under Midwestern (Weber, 1966) and Southeastern (Thurlow and Hiltbold, 1985) conditions, respectively. Assuming that Midwestern conditions are most similar to the Corn Belt, Northern Plains, Southern Plains, and Pacific Northwest tillage management regions (Fig. 3–2), and that Southeastern conditions most similar to Coastal Plains, Piedmont, and Eastern uplands; then approximately 72 and 28% of the soybean grown in the USA (USDA, 1979) have about 40 and 70% of their N needs met by fixation, respectively. Based upon the above assumptions and by also assuming that fixation for dry bean and peanut plants are similar to soybean plants, N_2 fixation would amount to about 48% of the 720 Gg fixed nationally in legume residues reported in Table 3–5 (USDA, 1978). Thus, about 350 Gg of N yr^{-1} or about 12% of the amount of N returned by the crop residues reported in Table 3–5 are from biological N_2 fixation by seed legumes.

Except for alfalfa, a major reduction in the use of forage legumes for biological N_2-fixation in cropping systems of the USA has occurred since about 1955 (Power, 1981; Power and Papendick, 1985). However, the feasibility of using legumes in cropping systems is receiving renewed interest (Ebelhar et al., 1984; Jones et al., 1983; Martin and Touchton, 1983; Power et al., 1983). Estimates of 7200 Gg of total annual biological N_2 fixation for USA's agriculture have been made. The bulk of symbiotically fixed N is immobilized within the herbage of the legume plant itself. Thus, much of it is removed with the harvested crop. Recently, Heichel (1986) identified that in legume-nonlegume crop sequences, the amount of N returned to the soil for use by the nonleguminous crop depends upon (i) the quantity of legume residue returned to the soil, (ii) the content of symbiotically fixed N in the residues, and (iii) the availability of the legume residue N to the succeeding nonlegume. Thus, to gain N-additions from forage legumes for succeeding crops, the legume must be managed to return N to the soil. The N available for incorporation into the soil depends upon the time of the season when incorporation occurs (Heichel, 1986) and the proportion of N-rich herbage that is incorporated into the soil as compared to N-poor crown and roots. The importance of the N-rich herbage is readily apparent from data in Table 3–6 from Heichel and Barnes (1984) which illustrates the relative amounts of N_2 fixed by alfalfa and removed from the soil for three cuttings of alfalfa during the seeding year. Heichel (1986) calculated that a typical alfalfa stand in the upper midwestern USA might contain no more than 6 kg of N ha^{-1} in root nodules.

For succeeding crops to benefit from symbiotically fixed N from forage legumes, they would presumably be grown in some type of crop rotation. Currently, much of the area used for growing forage legumes in the USA will be pastureland and hayland. Approximately 11 million ha of alfalfa were grown for hay in 1977 (USDA, 1979). Assuming that alfalfa stands are turned under at approximate 3-yr intervals, then about 3.6 million ha of alfalfa are turned under each year. The next assumption is an average fertilizer replacement value of 120 kg of N ha^{-1}, when alfalfa is managed as green manure or hay during its 3rd yr, plowed under in the fall and planted to a nonlegume the subsequent year (Heichel, 1986). Also, an average of 80% of the N in the alfalfa is assumed to have been

Table 3–6. Nitrogen budget for seeding year alfalfa showing the allocation of symbiotically fixed- and soil-derived N among plant parts (Heichel and Barnes, 1984).

Nitrogen budget component	Seeding year harvests		
	First (12 July)	Second (30 Aug.)	Third (20 Oct.)
Herbage yield (kg ha^{-1})	3.503	3.054	1.156
Total N yield (herbage, crown and roots) (kg of N ha^{-1})	118	127	59
Total N_2 fixed (kg of N ha^{-1})	57	102	34
Herbage	52	74	22
Roots and crown	5	28	12
Nitrogen from soil (kg of N ha^{-1})	61	25	25
Herbage	54	18	16
Roots and crown	7	7	9

symbiotically fixed (Heichel et al., 1984). Then, based upon the above assumptions, about 350 Gg of symbiotically fixed N yr^{-1} are returned annually to cropland from alfalfa in the USA.

Although other legumes are locally important, the assumption can likely be made (Power and Papendick, 1985) that the majority of forage legume N returned to cropland will be from alfalfa with other forage legumes accounting for some additional amounts; that does not result in a major change in the interpretation made here. The use of forage legumes in cropping systems is smaller than the potential appears to be. Reasons may be that they detract both space and time for the production of row crops. Also, the current widespread use of fertilizer N has greatly diminished the need to utilize legumes in cropping systems. Irrespective, there are new major opportunities to utilize forage as well as grain legumes as cover crops or catch crops in rotation with grain crops. Improved conservation tillage practices including no-till planting of a grain crop directly into a legume cover crop provides soil erosion control during periods of high erosion hazard. Additionally, it has the potential for reducing fertilizer N needs for the grain crop. For example, Ebelhar et al. (1984) estimated that hairy vetch (*Vicia villosa* Roth) in Kentucky supplied symbiotically fixed N equivalent to 90 to 100 kg ha^{-1} fertilizer N annually to maize while also serving as a winter cover crop to help provide soil erosion control.

Nutrient Resource Summary

The data from Tables 3–3, 3–4, 3–5, and from the discussions of the amounts of symbiotically fixed N added to the soil from soybean and alfalfa are summarized in Fig. 3–6. The authors recognize that these data are not complete in that the residues from a number of other crops produced on a limited scale are not included. Also, nutrient recycling from crop roots and livestock bedding wastes are not considered. Other

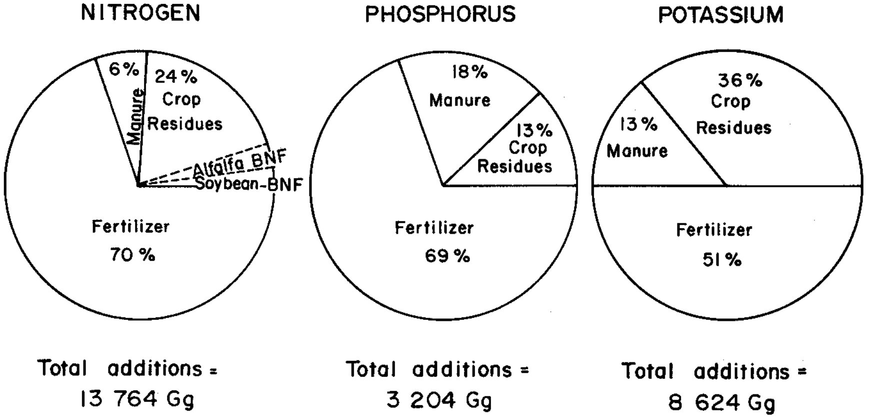

Fig. 3–6. Additions of N, P, and K to cropland soils of the USA from fertilizers and by return of crop residues and manure.

sources of nutrient additions such as from food processing wastes, municipal refuse, industrial organic wastes, sewage sludge and septage, and logging and wood manufacturing wastes are not included since they are generally considered of minor importance nationally (USDA, 1978). Irrespective, the relative amounts of nutrients added or returned to cropland soils from fertilizers, manures, and crop residues are shown. Such nutrients are important since a management choice is made whether to add these nutrients to the soil or not (fertilizers), or to return them to the soil, or remove them (i.e., crop residues) by burning, selling, or for some other purpose.

INFLUENCE OF CONSERVATION PRACTICES

Conservation practices influence the fate of plant nutrients in cropping systems. The degree of influence of conservation practices on the amounts of plant nutrients removed with the harvested crop, lost to the environment, or remaining in the soil for subsequent crop use (Fig. 3–3) needs to be evaluated. The following discussion is focused on situations where conservation practices are currently known to have a major impact and where sufficient data exist for an in-depth discussion. The evaluation will not be in-depth if conservation practices are only of minor importance or insufficient data exist.

Nutrient Losses

Soil Erosion

Soil erosion is perhaps the primary conservation problem on about one-half of U.S. cultivated croplands (Larson, 1981). A majority of the organic matter and available plant nutrients are near the soil surface and therefore are highly vulnerable to soil erosion. Off-site effects (Clark et al., 1985) as well as on-site effects of soil erosion are major national concerns. Loss of plant nutrients is a major consequence of soil erosion. Recent estimates of cropland losses of N, P, and K nationally are shown in Table 3–7 (Larson et al., 1983).

These data allow comparisons between amounts of plant nutrients from the various sources discussed previously and the amounts in eroded sediments. Data from Fig. 3–6 and Table 3–7 show that the ratio between total additions of N, P, and K and the total amounts of N, P, and K in eroded sediments are about 1.4:1.0, 1.9:1.0, and 0.2:1.0; respectively. Such a comparison does not consider removal of nutrients in harvested crops, leaching losses, surface runoff losses, or gaseous losses. Neither does it consider where eroded sediments and their associated nutrients are deposited, nor inherent fertility of the soil. Irrespective, these ratios indicate that the USA, on a national basis, is adding or returning more N and P but less K to the soil than is associated with eroded sediments. Over the long term, the relative differences between addition and return vs. erosion

Table 3-7. Total and available N, P, and K in eroded sediments (Larson et al., 1983).

Region	Nitrogen		Phosphorus		Potassium	
	Total	Available	Total	Available	Total	Available
	Gg					
Northeastern	300	55	75	1.5	2 252	45
Lake	622	114	107	2.1	3 643	73
Corn Belt	4 360	802	624	12.5	24 959	499
Northern Plains	2 068	380	293	5.9	11 711	234
Appalachian	676	124	169	3.4	3 381	67
Southeastern	202	37	101	2.0	1 007	20
Delta	478	88	141	2.8	4 220	84
Southern Plains	512	94	101	2.0	3 043	61
Mountain	176	32	64	1.3	2 550	51
Pacific	100	18	29	0.6	1 154	23
Total	9 494	1 744	1 704	34.1	57 920	1 158

of K appears to be of concern. However, the major crop production regions where the amounts of K (and N) are greatest in eroded sediments are the Corn Belt and the Northern Plains. In both regions, the soils have medium to high base supply and are relatively rich in organic matter. The ratios of total additions to total amounts in eroded sediments of N, P, and K for the Corn Belt and Northern Plains are about 1.0:1.0, 1.6:1.0, and 0.1:1.0 and 1.0:1.0, 1.2:1.0, and 0.1:1.0; respectively. Thus, ratios for both regions are lower than the national averages and it might be assumed that an overall net loss of N, P, and K may be occurring when the removal in the harvested crop, soil erosion, and other nutrient losses are considered collectively. Comparisons made at a regional or local level allow improved consideration of soil properties and overall interpretations. Also, conservation efforts need to be concentrated where erosion damage is greatest and not necessarily where the greatest amount of soil erosion occurs.

Soil Conservation and Organic Matter

Organic matter is primarily C (about 58% by weight) with a large reservoir of essential plant nutrients contained in it. Soil organic matter is also generally associated with the finer and more reactive clay and silt fractions of soils. Its proximity, and concentration near the soil surface (usually in the top 25 cm or less) and close association with plant nutrients in the soil, makes the erosion of soil organic matter a strong indicator of overall plant nutrient losses resulting from soil erosion. Thus, the effectiveness of soil conservation practices can also be evaluated based upon the amount of soil organic matter (organic carbon) associated with eroded sediments.

Tillage Effects—We used Land Resource Region M (USDA, 1981b) to demonstrate the effect of tillage on organic matter and nutrient losses due to water erosion. Land Resource Region M lies almost entirely within the North Central region and corresponds exactly to the Corn Belt Tillage

Management region identified by Allmaras et al. (1985) (Fig. 3–2 and Table 3–2). The following calculation procedures illustrate how soil survey and other data were used in conjunction with the Universal Soil Loss Equation (USLE), (Wischmeier and Smith, 1965, 1978) to calculate the effect of tillage on organic matter and nutrient losses due to water erosion.

Lindstrom et al. (1981) had previously assigned crop rotations to soil series and to slope-gradient classifications for determination of the cropping management (C) factor of the USLE. The assignment was based upon crop production statistics. The authors considered soil loss for three residue and tillage treatments. They are listed below.

1. Conventional tillage—No crop residue remaining on soil surface; equivalent to full moldboard plow, spring disk, and harrow.
2. Conservation tillage—3920 kg ha^{-1} of crop residue initially remaining on soil surface; subsurface tillage (chisel), 66% surface residue coverage.
3. No-till—3920 kg ha^{-1} of crop residue initially remaining on soil surface; 90% surface residue coverage.

The area of each soil association (Technical Committee on Soil Survey, 1960) by state and MLRA were determined and matched with the organic carbon content in the top 20 cm of soil as Franzmeier et al. (1985) reported for that soil association. A soil density of 1.4 g cc^{-1} was assumed for all soils to convert the organic carbon content Franzmeier et al. (1985) reported to percent organic carbon. Cultivated area, percentage of that area in each of four slope gradients (0–2, 3–5, 6–12, and >12%), and calculated soil loss rates by tillage treatment were obtained from Lindstrom et al. (1981). Next, a weighted average percent organic carbon was computed by state and MLRA from the soil associations found in each MLRA, fractions of the total area in each soil association, and the organic carbon content reported for each soil association (Franzmeier et al., 1985). Total erosion was calculated using previously calculated soil loss rates (Lindstrom et al., 1981) for each of the tillage treatments and area under each of the slope gradients. Organic carbon in eroded sediments was calculated by multiplying the weighted average percent organic carbon by soil erosion for each tillage treatment. Data from each MLRA (by state) were aggregated into totals for the Corn Belt Tillage Management Region. Organic nitrogen and organic phosphorus in eroded sediments were calculated assuming a ratio of organic carbon/organic nitrogen/organic phosphorous of 110:9:1 (Allison, 1973).

Since soil resource assessments and other activities associated with soil conservation are generally poorly correlated with soil testing activities, estimates that might be made of plant-available nutrients associated with eroded sediments are less reliable than are estimates of organic nutrients. Organic phosphorous, like organic nitrogen is concentrated in topsoil. Both are subject to mineralization and under favorable conditions supply a significant part of the N and P that plants needed. Therefore, the following discussion will be for organic nitrogen and phosphorous which will not always be closely correlated to plant-available N and P.

However, the loss of organic nutrients by erosion should be a good partial measure of overall nutrient losses.

Although loss of organic carbon (organic matter) is a direct function of soil loss, it is not a linear function. Since eroded materials frequently differ in composition from the original soil, the loss of nutrients may be expressed in terms of an enrichment ratio (ER) which is the ratio of the concentration of element in eroded soil material divided by the concentration of element in soil from which eroded soil material originated (Barrows and Kilmer, 1963). Organic matter is reported to have an average ER of 2.1 (Barrows and Kilmer, 1963). The value of ER reported for soil organic matter was assumed to be directly proportional for organic carbon with the constant organic carbon, nitrogen, and phosphorous ratio remaining at 110:9:1 (Allison, 1973). Separate enrichment ratios for N and P were not used since they are reported for total N and P rather than organic nitrogen and phosphorous (Barrows and Kilmer, 1963). Aggregation of the above calculations for Land Resource Region M are shown in Table 3–8.

Comparison of the amounts of organic carbon in eroded sediments (Table 3–8) for conventional tillage (49 000 Gg) to the total of that returned in animal manure (Table 3–4) and crop residue (Table 3–5) of about 40 000 Gg, shows the relatively high magnitudes and the overall importance of the return and management of organic residues to the soil organic matter budget in general. Although organic carbon is not necessarily misplaced from the landscape, these calculations show the potential for erosion to continually deplete organic carbon and emphasizes the importance of developing and adopting conservation practices to maintain, if not increase, soil C levels.

Slope and Tillage Effects—If targeting of soil conservation practices to the most serious soil erosion problems within MLRAs is to be accomplished, an understanding of the soil organic carbon, slope conditions, and amount of organic carbon in eroded sediments that may occur is needed. The basic unit for our computations was the soil series by slope gradient classification obtained from the SCS Conservation Needs Inventory (USDA, 1971). The area (converted to a percent of the total area)

Table 3–8. Annual soil erosion and amounts of organic carbon, nitrogen, and phosphorus in eroded sediments in the Corn Belt Tillage Management Region (Land Resource Region M) as influenced by tillage treatment.

Tillage treatment	Soil erosion	Organic carbon	Organic nitrogen	Organic phosphorus
		In eroded sediments†		
	Gg			
Conventional tillage	1 396 855	49 380	4 040	450
Conservation tillage	575 499	20 630	1 690	190
No-till	436 622	15 890	1 300	140

†An enrichment ratio of 2.1 was used for these calculations.

within an MLRA for dominating slope gradient and soil series was multiplied by the mid-range value of percent organic matter content from SOILS-5 data sheets for that soil series. Soil series were obtained by overlaying MLRA boundaries (USDA, 1981b) over Soil Association boundaries found in the North Central region (Technical Committee on Soil Survey, 1960). Weighted average soil organic carbon contents for each slope category were obtained for the four MLRAs of Land Resource Region M found in Minnesota and are shown in Table 3–9.

Multiplication of the values in Table 3–9 by the cultivated land area, cultivated soil loss rates, and an enrichment ratio of 2.1 (Barrows and Kilmer, 1963) for each of the tillage treatments and slopes reported in Lindstrom et al. (1981) give amounts of organic carbon in eroded sediments by MLRA, as shown in Fig. 3–7. By then applying an organic carbon to organic nitrogen to organic phosphorous ratio of 110:9:1 (Allison, 1973), estimates of erosion of all three nutrients were made. Figure 3–7 shows both the potential off-site and potential on-site impacts of soil erosion within each of the MLRAs. On-site losses refer to the rate (kg ha^{-1} per year) of nutrient losses due to soil erosion, whereas off-site losses mean total amount of nutrient losses (i.e., rate of nutrient loss as kg ha^{-1} times the area of the MLRA). The USLE (Wischmeier and Smith, 1978) is an entrainment model that does not account for sediment load loss or movement distance. Therefore, our calculations do not show that sediments are transported off of the landscape or where they are deposited. The length of each horizontal bar for a particular slope by tillage practice in Fig. 3–7 can be compared to the three scales shown on the horizontal axis of the graph to determine potential off-site losses of organic carbon, nitrogen, and phosphorous associated with eroded sediments. To evaluate potential on-site damage, the numbers from top to bottom on the left inside part of each graph give the kg ha^{-1} per year of organic carbon, nitrogen, and phosphorous in eroded sediment as a function of slope and tillage practice.

The high degree of load loss that might be expected, especially for the 0 to 2 and 3 to 5% slope conditions, is important to recognize in the following discussion of Fig. 3–7. In terms of nutrients associated with eroded sediments, the 0 to 2 and 3 to 5% slopes were generally highest (MN 102 and 103) because of the large areas of cultivated land and the

Table 3–9. Calculated average percent organic carbon in topsoil by slope category in Minnesota MLRAs 102, 103, 104, and 105.†

Slope percent	Mn 102	Mn 103	Mn 104	Mn 105
	% organic carbon			
0–2	3.59	4.43	2.80	2.23
3–5	2.82	2.48	2.00	1.35
6–12	2.33	1.80	2.00	0.89
>12	1.74	0.65	0.64	0.62

†Calculated values in this table were evaluated for their appropriateness by Dr. R. H. Rust of the Minnesota Soil Survey Staff, St. Paul (1986 personal communication, St. Paul).

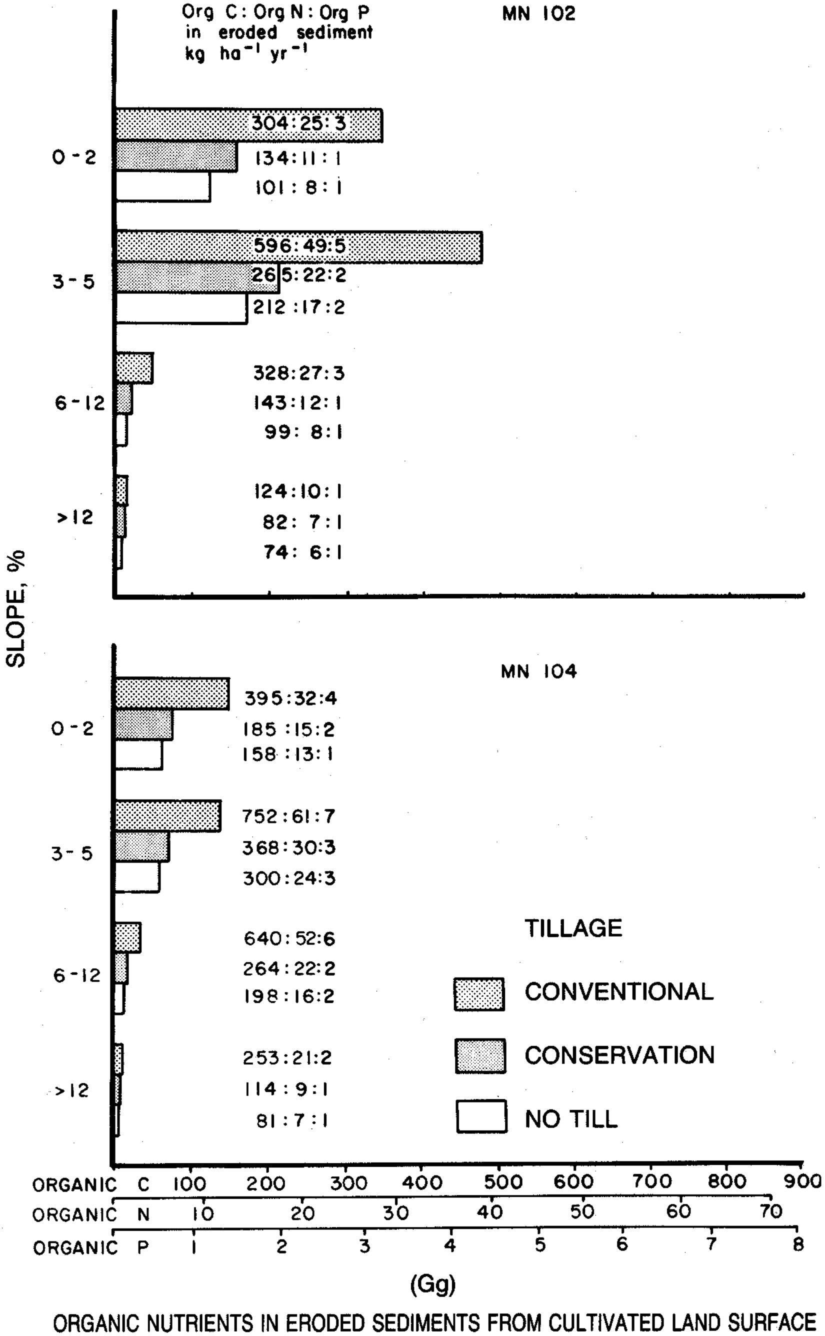

Fig. 3–7. Organic nutrients in eroded sediments from cultivated land surface as a function of slope and tillage.

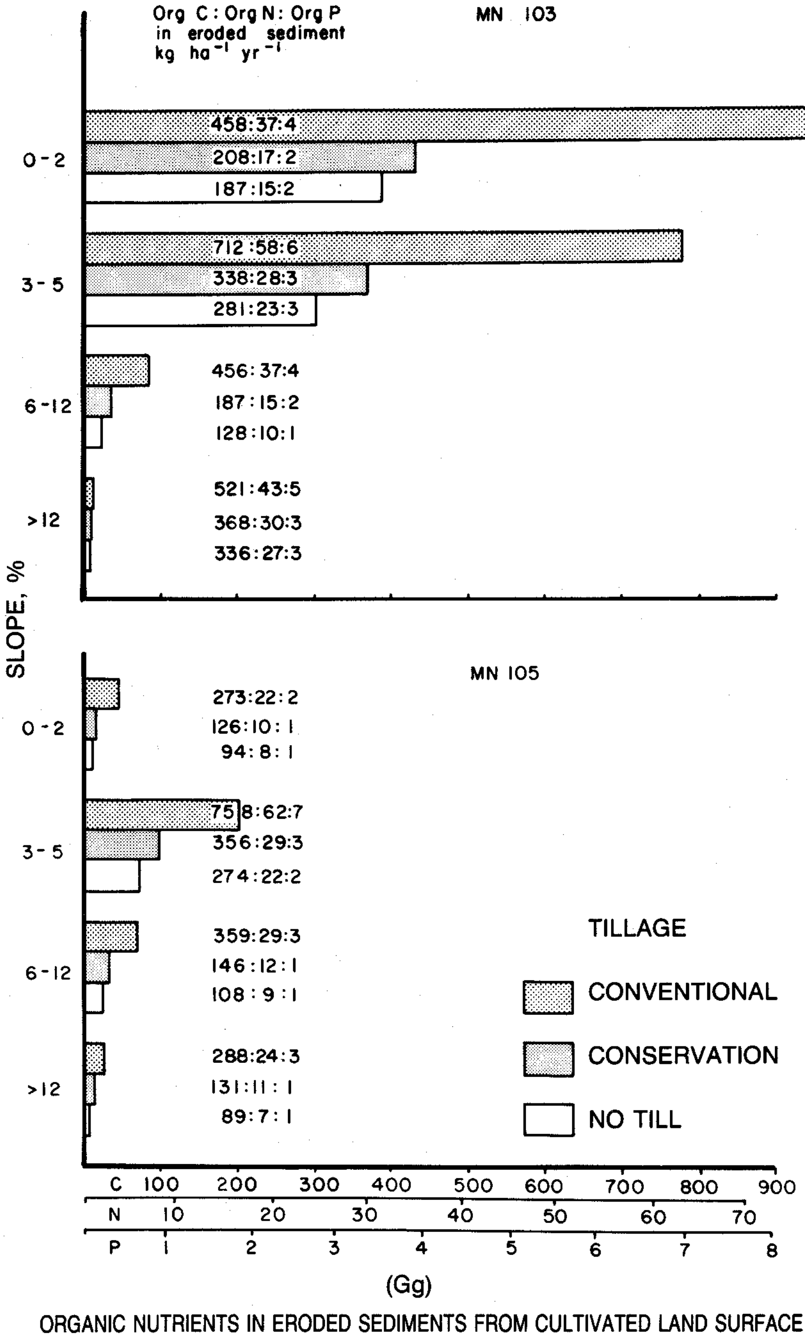

Fig. 3–7. Continued.

higher soil organic matter contents. Organic carbon, nitrogen, and phosphorous associated with eroded sediments are generally much less for MN 104 and 105 than for MN 102 and 103 because of smaller cultivated area and/or lower soil organic matter contents. In addition, MN 105 and 104 have likely been cultivated for many more years than MN 103 and 102. The 3 to 5% slopes had the highest rates of organic carbon, nitrogen, and phosphorous loss per hectare (Fig. 3–7), while slopes of > 12% had the least. The lower rates of nutrient loss per hectare from the steepest slopes resulted from low organic matter content of soil from these slope conditions (Table 3–9).

Conservation tillage decreases the amount of organic nutrients associated with eroded sediments by about half; some additional decrease is obtained from no-till (Fig. 3–7). Where these practices are not sufficient to protect the soil resources or prevent loss of soil productivity, targeting of additional conservation practices may be necessary.

Other Losses

As shown in Fig. 3–3, other types of nutrient losses that conservation practices might affect are gaseous-, leaching-, and surface-runoff losses. Conservation tillage practices are of increasing interest because of their beneficial effects of reducing soil erosion and evaporative water losses. Reductions in the loss of soil organic matter and the retention of nutrients are additional benefits. No-till and other types of conservation tillage are reported to maintain larger reservoirs of potentially mineralizable nutrients, especially N, near the soil surface than does conventional tillage (Doran, 1980). Microbial populations with higher numbers of facultative anaerobes and denitrifiers have also been observed for no-till than for conventionally tilled soils (Doran, 1980). Thus, a greater potential for anaerobic metabolism and denitrification may occur with no-till than with conventional tillage.

Changes in soil water storage with conservation tillage are the result of four processes: suppressed overland flow, enhanced infiltration, more downward redistribution of water in the soil profile, and decreased evaporation. In a recent review, Allmaras et al. (1985) identified studies indicating that surface residues significantly reduce the velocity of overland flow so that infiltration is increased even if the infiltration rate is low.

To the degree that reduced tillage systems maintain larger reservoirs of potentially mineralizable N near the soil surface, the resulting question is whether increased infiltration associated with conservation tillage is conducive to leaching of soluble nutrients through and below the root zone. However, recent research by Elliott (Fort Collins, CO, 1986, personal communication) shows less leaching of nitrate (NO_3^-) under no-till than for stubble mulch or bare fallow in western Nebraska. He concluded that this decreased leaching was probably a result of the maintenance of soil structure and preferential flow of water down macropores or through inter-aggregate pore space. Higher moisture content, but less NO_3^- leaching in the no-till treatment indicated that NO_3^- was likely by-passed by preferential water flow through macropores. Nitrates resident within the aggregates and the need for diffusion of solutes out of aggregates may have resulted in lower NO_3^- concentrations in the draining soil water.

When soluble nutrients are on or near the soil surface (e.g., NO_3^-), they are usually leached into the soil by infiltration during the first part of a storm. Thus, the more infiltration there is before runoff begins, the lower the NO_3^- content of the runoff water. However, if the infiltrating water moves laterally and returns to the surface (interflow), its dissolved nutrient load is added to the overland flow. Stewart et al.'s (1976) report provides an overview on the control of water pollution from cropland. Surface runoff losses of dissolved nutrients are generally a small percentage of the total load of sediment transported nutrients (Gebhardt et al., 1985). Leaving crop residues on the land surface decreases runoff, but may not change the nutrient concentration of the runoff. For example, the effectiveness of conservation tillage for reducing soluble P in surface waters may depend on whether fertilizer is incorporated into the soil or not. If broadcast fertilizer is incorporated (or banded) into soil, reductions in P load are common under conservation tillage (Gebhardt et al., 1985). However, leaching of P from crop residues under no-till may increase the concentration of P in surface runoff waters while the soluble N load may not be affected at all (Stewart et al., 1976).

Nutrients Removed

The role of conservation practices for influencing the removal of plant nutrients in the harvested product (Fig. 3–3) must, to a large degree, be judged by the effect of conservation practices on increasing or decreasing crop yields. This assumes that the concentration of nutrients in the harvested product (e.g., grain) is essentially constant. Recently, Allmaras et al. (1985) reviewed research on crop yield responses to conservation tillage systems by TMR (Fig. 3–2). They identified major deterrents to the effective use of conservation tillage for maintaining or increasing crop yields as compared to conventional tillage including: weed problems; the lack of effective and/or adapted management inputs; nonavailability of adapted crops or cultivars; insects and/or disease problems; and delayed planting or poor stands resulting from low soil temperatures, some soil properties (e.g., wet or high clay soils), or large amounts of crop residues.

Irrespective of the difficulties encountered in using conservation tillage, increases in crop yield are generally possible in all TMRs with significant increases possible in the Northern Great Plains. Where such increases do occur, the use of conservation practice(s) is resulting in increased removal of plant nutrients in the harvested crop. In addition, increased amounts of nutrients are taken up into crop residues to be recycled if the residues are returned to the soil.

Remaining Nutrients

The role of conservation practices for influencing the amount of plant nutrients remaining in the soil (Fig. 3–3) for subsequent crop use was described earlier in Eq. [1]. Maintenance of a fertile soil is closely associated with this reservoir of plant nutrients. Almost without exception, the reservoir of inorganic plant nutrients and those temporarily immobilized in various organic fractions within the soil are the prime sources of mineral nutrients taken up by the plants during the growing season.

As has been discussed earlier, organic matter improves soil fertility and a number of other desirable soil properties. Some cropping systems result in a build-up of soil organic matter, whereas others result in decreases. It is difficult to devise any cropping system that will prevent some decrease in the organic matter content in soils after they are plowed out of grass and put into grain production for the first time. However, after this initial decrease, various conservation and fertilization practices can be employed to prevent further decreases or even increase soil organic matter content (Power and Legg, 1978). The maintenance of or even restoration of soil organic matter levels may be one type of long-term measure of the effectiveness of conservation practices in maintaining soil productivity.

FUTURE ISSUES

Assessment Technologies

Targeting of appropriate soil conservation practices to maintain or improve soil productivity while controlling losses of plant nutrients by soil erosion, surface runoff, leaching, and perhaps even gaseous losses will require assessments. Guidelines will need to consider changes in soil chemical and physical properties across the landscape as influenced by conservation practices. At present there is only limited information on the effects of (i) landscape characteristics (slope and slope length), (ii) soil management practices (tillage), and (iii) crop management practices (double cropping, cover crop, and residue cover) on nutrient losses. If nutrient and organic matter data bases are available, then at least data bases, such as the Natural Resources Inventory (USDA, 1982), could be used to assess the changes in chemical aspects of soil productivity due to erosion. However, methods still need to be devised to improve assessments of leaching, gaseous, and surface runoff losses. Such methods will help delineate landscape, soil, or crop management factors that if managed properly will help preserve inherent soil fertility and thus soil productivity. Also, such methods require the availability and use of data bases. Availability of data is inadequate and techniques difficult for broad-scale assessments of the affects of conservation practices on improving plant nutrient management for crop production. However, such evaluations are needed and can help to identify those conservation practices that are most effective. Improvement and transfer of conservation practices to other soils and other geographical regions requires certain types of additional data as follows.

Delineation of Tillage Management Regions

The TMRs are too general in terms of conservation needs and functions. Further assessment is needed of the subdividing TMRs based upon soil fertility constraints for adoption of conservation tillage practices.

Improved Soil Test Data Base

To assess the influence of conservation tillage practices on future plant nutrient management, the current fertility status of soils, updated as often as feasible, is needed. Inventory of inherent fertility status could be accomplished through national coordination of existing and future soil test data bases in terms of nutrient amounts and not percent of samples in various qualitative categories (i.e., high, medium, and low). Scientific shortcomings of the soil test data bases in reporting quantitative soil fertility is recognized. However, this type of data base is essential for assessing changes in fertility status due to changing soil and crop management practices such as the increasing use of conservation tillage.

Soil Organic Matter Data Base

The organic matter status of soil allows evaluation of changes in the status of this resource due to changes in management schemes. Except for the organic matter data by soil association for North Central states (Franzmeier et al., 1985), there is no unified data base on organic matter status of U.S. soils. Soil organic matter and inherent fertility status of soils is routinely assessed during soil survey undertakings. The authors feel a national effort is needed to synthesize organic matter and fertility status by soil type, soil association, and major land resource area.

Merging of Data Bases

Assessment of the changes in on-site soil fertility status and possible off-site damage potential as influenced by soil (slope and tillage) and crop (double-cropping, cover crop, and residue cover) factors will require the merging of a soil test data base with soil resource data bases, such as those containing soil organic matter status, soil survey, soil erosion data, and possibly others.

Control Technologies

Indigenous soil nutrient resources, as well as nutrients that are added (fertilizer) or returned (crop residues, manures, etc.) to the soil must all be effectively managed. It is encouraging to observe the trend of increased use of conservation tillage for cropland in the USA. However, the complex interactions of conservation practices with improved plant nutrient management are still poorly understood. Even through conservation tillage has been the primary conservation practice that we have discussed, the use of a number of other water erosion (Laflen et al., 1985) and wind erosion (Fryrear and Sidmore, 1985) control practices may also be necessary. Much continued research is needed on the joint goals of continuing to improve crop yields while minimizing environmental degradation.

Increased use of conservation practices, especially conservation tillage, is helping to alleviate the effects of soil erosion on losses of nutrients and organic carbon from cropland. However, the overall effects of conservation practices on other types of losses, such as from gaseous losses, leaching, and surface runoff of dissolved nutrients and C is much less well understood. Even though these other types of nutrient and organic carbon losses may be assumed to be small relative to those resulting from soil erosion, their on-site and off-site effects (e.g., N leaching into groundwater) may result in significant environmental degradation. Nonetheless, the development of improved conservation practices to decrease the total loss of on-site nutrients is a necessary and worthwhile goal and requires a full understanding of the role of soil fertility and organic matter as critical components of production systems.

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